

# Book Chapter - Radial Line Slot Array (RLSA) Antennas

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## Chapter

# Radial Line Slot Array (RLSA) Antennas

*Teddy Purnamirza*

## Abstract

Radial line slot array (RLSA) antenna was initially developed for satellite antenna receivers at a frequency of Ku-band. The success of this development inspired researchers to continue the study to other bands and other applications, such as Wi-Fi at 5.8 GHz. Wi-Fi applications need small antennas that lead to the diminution of RLSA antennas. Small-RLSA antennas experienced high reflection due to the small number of slots. One of the techniques that effectively eliminates the reflection was developed and named as extreme beamsquint technique. Several researches have successfully developed small-RLSA antennas by implementing this technique for Wi-Fi applications. Furthermore, for the future, it is possible to widen the researches to other frequencies and other features of RLSA antennas such as multibeam, multiband, and diminution by cutting off RLSA antennas.

**Keywords:** RLSA antennas, extreme beamsquint, small RLSA, RLSA for Wi-Fi, future RLSA antennas

## 1. Introduction

Radial line slot array (RLSA) antennas are a type of cavity or waveguide antennas. These antennas were firstly developed for satellite receivers as an option besides parabolic antennas. Unlike parabolic antennas, RLSA antennas have an advantage of having feeders at the back of the antenna, so that the feeders do not block out incoming signals. The other advantage is their flat shape so that they are more aesthetic compared to parabolic antennas. Nowadays, RLSA antennas are developed for different frequency applications such as Wi-Fi, 5th G, etc.

This chapter discusses briefly all about radial line slot array (RLSA) antennas, especially for the linearly polarized (LP)-RLSA antennas. Firstly, in Section 2, the review of RLSA antennas including the development of RLSA antennas, their applications, their development obstacles and the developed technique to overcome the obstacles are reviewed. Secondly, in Section 3, the theory of RLSA antennas is explained which includes how the antenna works and several equations to calculate antenna parameters. Thirdly, in Section 4, the mechanism of reflections in RLSA antennas, which is due to slot reflections and due to remaining power in antenna perimeter, is discussed. Fourthly, in Section 5, the theory of extreme beamsquint technique is also explained in detail. Lastly, in Section 6, the idea of future research in topic of RLSA antennas is briefly explained, including the idea of cutting off RLSA antennas to smaller size, multibeam RLSA antennas, utilizing background as

radiating element and multiband RLSA antennas. It is hoped that the ideas can inspire researches for the next development of RLSA antennas.

## **2. Review of RLSA antenna developments**

Kelly introduced the concept of RLSA antennas in the 1950s [1]. Although Kelly could produce a high-gain RLSA antenna, the structure of the antenna feeder was still complex, leading it to be costly.

In 1988, Ando et al. proposed a RLSA antenna at a frequency of 12 GHz. This antenna was designed using the technique of slot arrangements. The technique aims to produce a uniform-aperture distribution. This antenna has a double-layer cavity and exhibits a good linear polarization. Ando also proposed a beamsquint technique to improve the poor reflection coefficient in linearly polarized RLSA antennas [2, 3]. In the same year, by applying a reflection coefficient suppression and slot coupling technique, Ando successfully designed a LP-RLSA antenna for satellite applications at 12 GHz. This antenna has the efficiency of 76% and the gain of 36 dB [4–6]. Takada et al. introduced a technique to improve the reflection coefficient using a reflection cancelling slot technique. This technique successfully improved the reflection coefficient of RLSA antennas from  $-2$  to  $-10$  dB [7]. Endo et al. designed an optimum thickness of double-layer RLSA antennas in order to realize the mass production of thinner RLSA antennas [6].

In 1990, Ando et al. furthermore introduced a circularly polarized RLSA (CP-RLSA) antenna. This antenna utilizes a single-layer cavity instead of a double-layer cavity. This simpler cavity structure improves the complexity of RLSA fabrications and can achieve the gain of 35.4 dBi and the efficiency of 65%. Ando used two techniques to improve the antenna performance. The first is the technique of varying the slot length and slot spacing used to event out the aperture illuminations of the antenna. The second is the technique of matching spiral used to reduce the reflection of the residual power at the antenna perimeters [8, 9]. In 1991, Takashi et al. proposed the technique of varying the slot length and spacing. Utilizing this technique Takahashi proposed several high-efficiency single-layer RLSA antennas with the diameter of 25–60 cm. These antennas can achieve efficiencies of between 70 and 84% [10]. Furthermore, Takashi et al. produced and marketed a 78% efficiency, 32.6 dB gain and single-layer RLSA [11–13].

Australian researchers started to investigate RLSA in 1995. They reported several investigations to design LP-RLSA antennas for satellite receivers. These investigations used the combination of the theoretical and experimental approach. The availability of low-cost materials (polypropylene) and low-cost fabrication also become a consideration in these researches. In 1997, Davis reported a 60 cm diameter LP-RLSA prototype designed using the reflection cancelling slot technique. This technique can overcome the inherent poor reflection coefficient of LP-RLSA antennas [4]. Davis and Bialkowski also successfully tested a RLSA antenna designed utilizing the reflection cancelling slot technique and a beamsquint value of  $20^\circ$  [14, 15]. Furthermore, Davis and Bialkowski reported an investigation of LP-RLSA antennas utilizing the beamsquint technique for several squint angles. This technique successfully improved the reflection coefficient under  $-25$  dB [16]. Davis integrated the report of [2, 4, 7, 11] to form a beam synthesis algorithm used to calculate the design parameter of LP-RLSA antennas [17].

Due to the successful development of RLSA antennas for satellite applications, researchers tried to bring RLSA antennas into small antenna application for Wi-Fi devices. However, the design of small-RLSA antennas was not easy since small-size RLSA antennas normally performed high reflection coefficient [18–20]. Hirokawa

et al. used a technique for matching slot pair in order to reduce the remaining power at the antenna perimeter of small-aperture RLSA, so that this technique can minimize the reflection coefficient [21, 22]. Akiyama et al. also used the same technique for matching slot pair [23, 24]. However, the technique for matching slot pair is only used to radiate the remaining power at the antenna perimeter and does not contribute to the antenna gain. Reference [25] introduced the use of long slots in order to increase the ability of slots to radiate power, so that it can reduce the remaining power at the perimeter of small-aperture RLSA antennas, thus reducing the reflection coefficient. However, although this method can reduce the reflection coefficient, this method also can decrease the antenna gain. This is because that the long slots cannot radiate a focus power.

In 2002, Malaysian and Australian researchers started to investigate the application of RLSA antennas for wireless LANs. Tharek and Ayu successfully fabricated a low-profile RLSA antenna at a frequency of 5.5 GHz with a broad radiation pattern of  $60^\circ$  used for indoor wireless LANs [26]. Bialkowski and Zagriatski investigated the design of RLSA antennas for wireless LANs and successfully fabricated a dual-band 2.4/5.2 GHz antenna [27, 28]. Furthermore, Imran et al. reported the design and test of RLSA antennas for outdoor point-to-point applications at the frequency of 5.8 GHz [29–31]. However, this design utilized a beamsquint technique that is similar with the technique used to design RLSA antennas for satellite applications. Hence, the diameter of this antenna is still considered large with a diameter of 650 mm, so that it is not applicable for small Wi-Fi devices. Islam reported the utilization of low-cost FR4 materials to fabricate RLSA antennas at the frequency of 5.8 GHz for wireless LANs. This invention is quite innovative since FR4 materials are a low-cost material and easy to be fabricated [32, 33]. However, there are some drawbacks in designing this antenna, such as a design of overlap slots, a loss cavity due to the use of several FR4 boards and the use of material loss of FR4. These all lead to low gain (only 8 dB) and low bandwidth (75 MHz).

Purnamirza et al., in 2012, introduced a technique called extreme beamsquint technique in order to overcome the problem of high reflection in small-RLSA antennas [34]. This technique uses the beamsquint values higher than  $60^\circ$ . The theory of how the high values of beamsquint can significantly minimize the reflection coefficient is explained. Purnamirza also developed RLSA antennas that mimic the specification of other types of antenna that is available in markets [35–38].

### 3. Basic theory of RLSA antennas

This section discusses the theory of RLSA antennas including the structure, the theory of how RLSA antennas work as well as several formulas to design RLSA antennas.

#### 3.1 Structure of RLSA antennas

**Figure 1** shows the illustration of the structure of a RLSA antenna. The figure shows the structure of RLSA antennas consisting of a radiating element, a cavity, a background and a feeder. The radiating element usually is a circular plate made of metals, such as aluminium, copper or brass. The radiating element consists of many slot pairs. One slot pair acts as one antenna element so that all the slot pairs form an array antenna. The background is a metal plate just like the radiating element, but the background does not have slots. The cavity is a dielectric material that has the form of a tube. Together with the radiating element and the background, the cavity operates as a circular waveguide that guides the signal from the feeder to propagate

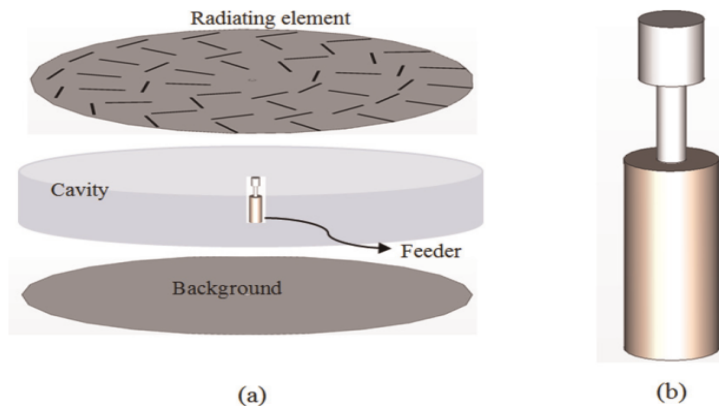


in radial direction. The feeder is a part of RLSA antennas used to feed signals from a transmission line into the antenna.

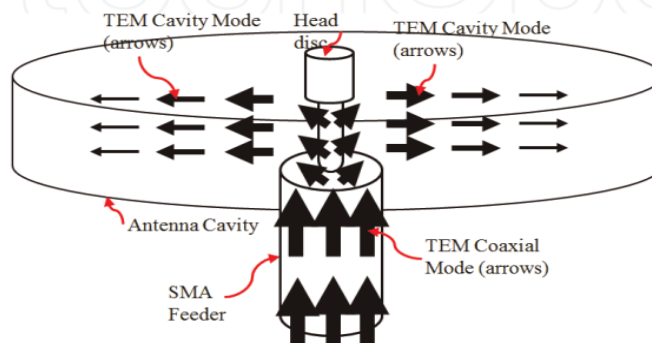
### 3.2 How RLSA antennas work

**Figure 2** shows the wave propagation mechanism including TEM cavity mode and TEM coaxial mode. The feeder placed in the centre of the antenna cavity feeds the electromagnetic power (indicated by the arrows). The feeder is an ordinary SMA feeder, which is modified by adding a head disc. The head disc has a function to convert the electromagnetic power from a TEM coaxial mode into a TEM cavity mode (a radial mode), so that the electromagnetic power fed by the feeder will propagate in a TEM mode and in a radial direction within the antenna cavity.

When the power passes the slot pair, some amount of the power escapes through the slot pair and radiates as illustrated in **Figure 3**. Hence, the slot pair can be considered as one antenna element. Since there are many slot pairs (thousands in normal-size RLSA antennas), all the slot pairs will form an array antenna. Therefore, this is the reason why 'array' word is included in the name of RLSA.



**Figure 1.** (a) The component of RLSA antennas. (b) The magnified view of the feeder [39].



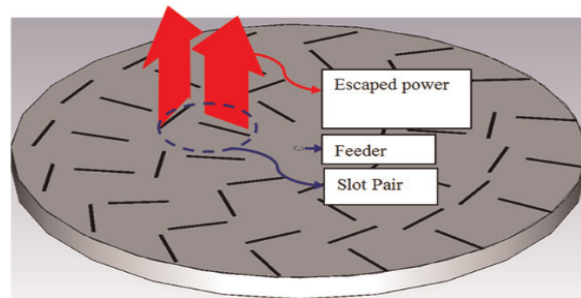
**Figure 2.** Illustration of the TEM cavity mode and the TEM coaxial mode [39].

### 3.3 Polarizations

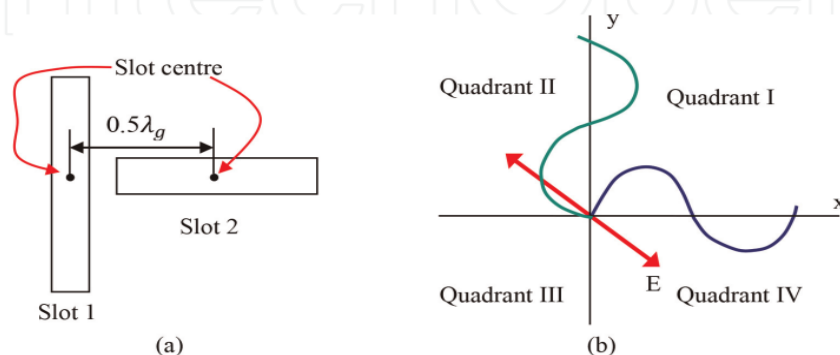
A slot pair, which represents a signal source in RLSA antennas, is located in the top surface of the radiating element of a RLSA antenna. A linear polarization in the RLSA antenna can be produced by combining two signals from the slot pair.

**Figure 4a** shows the illustration of the slot pair. The signal from Slot 1 and the signal from Slot 2 have a phase difference of  $180^\circ$  or  $\pi$  radians since Slot 1 and Slot 2 have the distance of half wavelength ( $0.5\lambda_g$ ) to each other. Since the orientation of Slot 1 and Slot 2 is perpendicular to each other, the signals from Slot 1 (at y axis) and Slot 2 (at x axis) are also perpendicular to each other, as shown in **Figure 4b**.

**Figure 4b** shows that when Signal 1 is increasing in positive values, Signal 2 is decreasing in negative values. Since their position is perpendicular to each other, the resulting wave becomes a line in Quadrant II. When Signal 1 is decreasing towards zero and Signal 2 is increasing towards zero, the resulting signal will be a line in Quadrant II but with a shorter length compared to the line in the previous case. When Signal 1 is decreasing in negative values and Signal 2 is increasing in positive values, then the resulting signal will be a line in Quadrant IV. When Signal 1 is increasing towards zero and Signal 2 is decreasing towards zero, then the resulting signal will be a line in Quadrant IV but with the shorter length compared to the line in the previous case. Now, we can understand that the resulting signal of Signal 1 and Signal 2 results in a signal that looks like a straight line where the



**Figure 3.**  
Illustration of the power escaping from the slot pairs [39].



**Figure 4.**  
Polarization establishment in a linearly polarized RLSA [39]. (a) slot pair position (b) signal of each slot.

length changes as a function of time; this is the reason why its name is 'linear polarizations'.

### 3.4 Orientation of the slot in RLSA antennas

**Figure 5** shows the position of the slots (indicated by 'A' and 'B') and the squint of the inclination angles of the slots (indicated by  $\theta_1$  and  $\theta_2$ ). The slot pair must be located in the correct position on the radiating surface of RLSA antennas. The slot pair must be located in different and unique positions in order to prevent overlapping between them.

Equations (1) and (2) express the squint of the slots obtained by the beamsquint technique [4, 14–17, 39–43]:

$$\theta_1 = \frac{\pi}{4} + \frac{1}{2} \left\{ \arctan \left( \frac{\cos(\theta_T)}{\tan(\phi_T)} \right) - (\phi - \phi_T) \right\} \quad (1)$$

$$\theta_2 = \frac{3\pi}{4} + \frac{1}{2} \left\{ \arctan \left( \frac{\cos(\theta_T)}{\tan(\phi_T)} \right) - (\phi - \phi_T) \right\} \quad (2)$$

where  $\theta_1$  is the inclination angle of Slot 1;  $\theta_2$  is the inclination angle of Slot 2;  $\theta_T$  is the beamsquint angle in elevated direction;  $\phi$  is the azimuth angle of Slot 1 and Slot 2 position; and  $\phi_T$  is the beamsquint angle in azimuth direction.

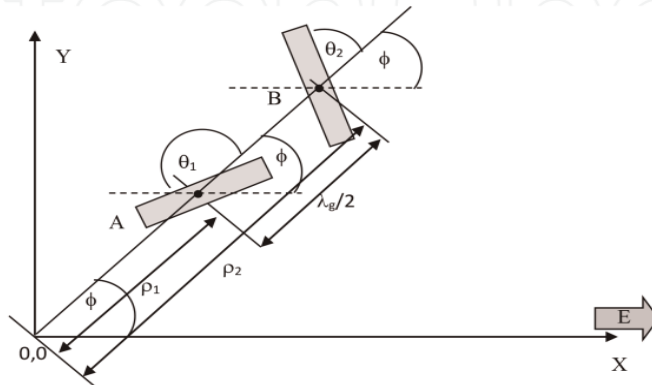
### 3.5 Arrangement of slot pairs

**Figure 6** shows the geometrical arrangement of a slot pair or also called a unit radiator. The arrangement of the unit radiator in the radiating surface of RLSA antennas must be carefully calculated and drawn since a little deviation of the unit radiator position will rapidly decrease the performance of RLSA antennas.

Based on **Figure 6**, the distance of a particular unit radiator from the centre point of RLSA antennas is expressed in Eq. (3) [4, 14–17, 39–43]:

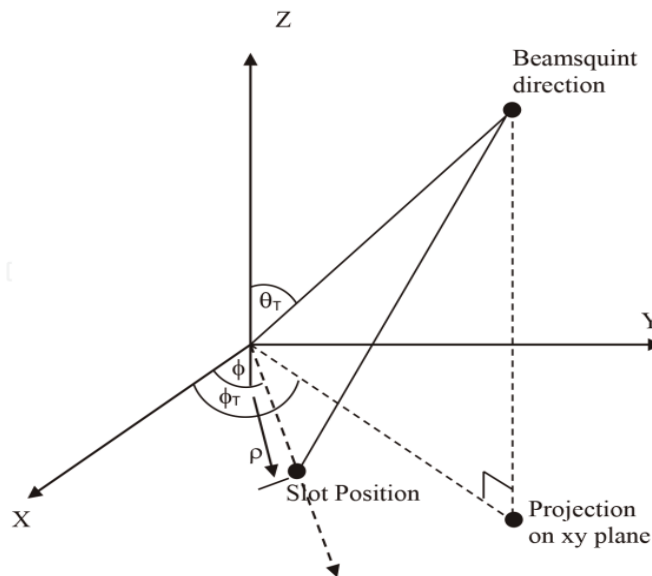
$$\rho_p = \frac{n\lambda_g}{1 - \xi \sin \theta_T \cos(\phi - \phi_T)} \quad (3)$$

Where  $\xi = \frac{1}{\sqrt{\epsilon_r}}$



**Figure 5.**  
Slot pair geometry [39].





**Figure 6.**  
Geometrical arrangement of a unit radiator [39].

Equation (4) expresses the distance between two adjacent unit radiators located in two different rings (the distance in the radial direction) [4, 14–17, 39–43]:

$$S_{\rho} = \frac{\lambda_g}{1 - \xi \sin \theta_T \cos (\phi - \phi_T)} \quad (4)$$

Equation (5) expresses the distance between two adjacent unit radiators in a same ring (the distance in the azimuth direction) [4, 14–17, 39–43]:

$$S_{\phi} = \frac{2\pi\lambda_g}{\sqrt{1 - \xi^2 \sin^2 \theta_T}} \frac{q}{p} \quad (5)$$

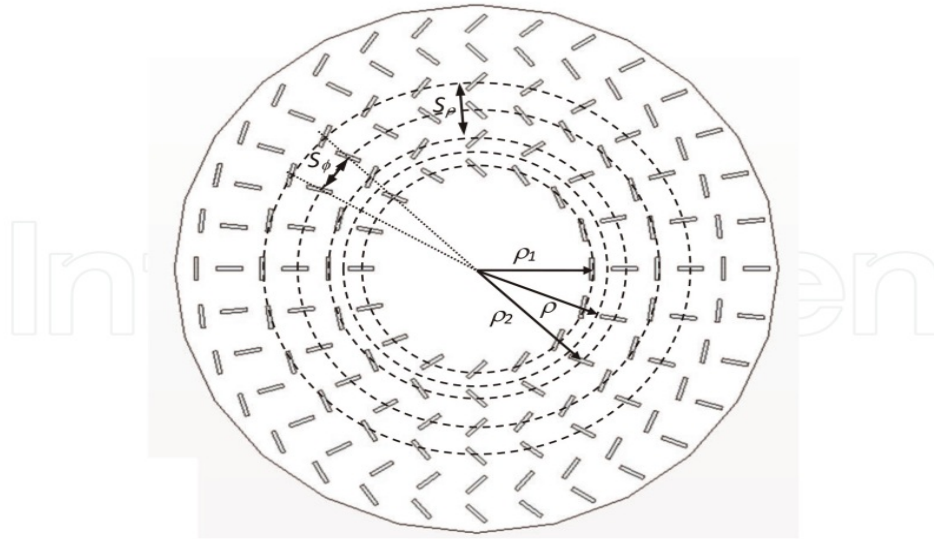
where  $\lambda_g$  is the length of the wavelength inside the cavity of RLSA antennas;  $\epsilon_r$  is the relative permittivity of the cavity of RLSA antennas.

$n$  is the ring numbers (1,2,3, etc.);  $q$  is the integer numbers (1, 2, 3, etc.) that express the distance of the innermost ring from the centre of RLSA antennas; and  $p$  is the number of unit radiators in the innermost ring.

The parameters of  $S_{\rho}$ ,  $S_{\phi}$ ,  $\rho_p$ ,  $\rho_1$ , and  $\rho_2$  are shown in **Figure 7**. Since the distance from the centre of the unit radiator to Slot 1 or Slot 2 is ' $\lambda_g/4$ ', Eqs. (5)–(7) express the distance of slots from the centre of antennas [4, 14–17, 39–43]:

$$\rho_{\rho 1} = \frac{(n - 1 + q - 0.25)\lambda_g}{1 - \xi \sin \theta_T \cos (\phi - \phi_T)} \quad (6)$$

$$\rho_{\rho 2} = \frac{(n - 1 + q + 0.25)\lambda_g}{1 - \xi \sin \theta_T \cos (\phi - \phi_T)} \quad (7)$$



**Figure 7.**  
Definition of some slot parameters [39].

### 3.6 Length of slots

The length of the slots on the radiating surface of RLSA antennas must be varied in order to achieve a uniform aperture illumination. The farther a slot from the centre of the antenna, the longer the length of the slot will be. The length of the slot is the function of  $\rho$  that is the distance of the slot from the centre of the antennas, as expressed by Eq. (8) [42]:

$$L_{rad} = (4.9876 \times 10^{-3} \rho) \frac{12.5 \times 10^9}{f_0} \quad (8)$$

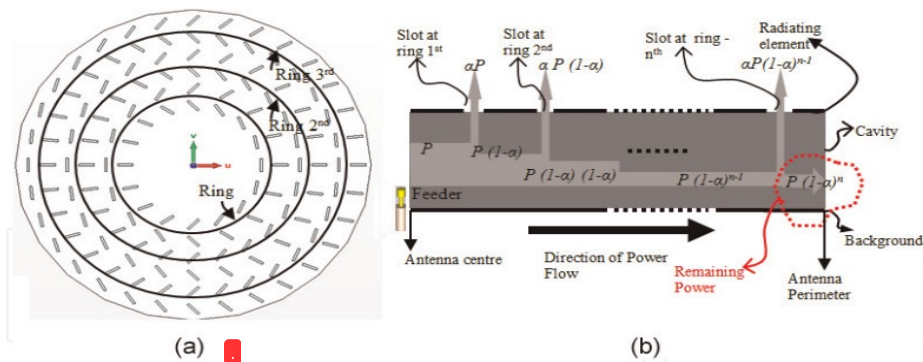
The formula in Eq. (8) is an approximate formula. To get an accurate formula, we need to do some measurements and experiments.

## 4. Reflection in small-RLSA antennas

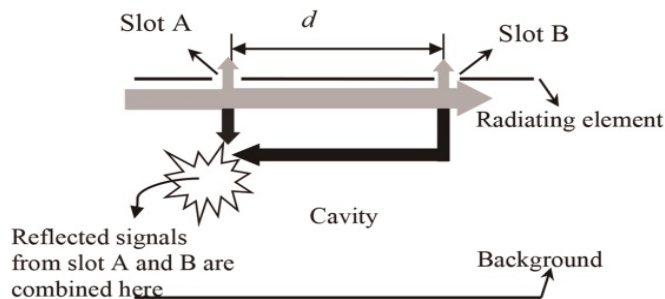
### 4.1 Signal reflection due to remaining power

The power ( $P$ ) comes from the feeder, which is located at the centre of the antenna, and flows towards the antenna perimeter, as illustrated in **Figure 8b**. When the power passes the slots, some amount of the power radiates through the slots. The power inside the cavity will decrease every time the power passes the slots and will continue to decrease until the power reaches the antenna perimeter. Equation (9) expresses the remaining power ( $P_R$ ) at the antenna perimeter [42]:

$$(P_R) = P (1 - \alpha)^n \quad (9)$$



**Figure 8.**  
(a) Top view of RLSA. (b) Cut view of a RLSA antenna and the power flow mechanism inside the RLSA cavity [39].



**Figure 9.**  
Illustration of the reflected signals from the slot [39].

Equation (9) shows that the amount of the remaining power depends on the number of rings ( $n$ ), which is also proportional to the number of slots. For small-RLSA antennas, which have a small number of slots, the amount of the remaining power at the antenna perimeter will be high. Part of this remaining power will be reflected back to the feeder and result in a high signal reflection, thus increasing the reflection coefficient. For normal-size RLSA antennas, which have thousands of slots, the remaining power at the antenna perimeter is very small so that its effect to the signal reflection is neglected.

#### 4.2 Signal reflection due to the reflected signal from slots

Figure 9 shows the front cut view of a RLSA antenna and the signal flow within the cavity of the RLSA antenna. The grey arrows represent the signals that flow from the centre of the RLSA antenna to the antenna perimeter, and the black arrows represent the reflected signal from the slots. Figure 9 shows that since the distance between the slots ( $d$ ) is  $\lambda_g/2$ , the signal from slot 'A' will travel for  $\lambda_g/2$  to reach 'B'. At 'B', some of the signal will be reflected back and travel for another  $\lambda_g/2$  to reach 'A'. Therefore, the reflected signal from slot 'A' and slot 'B' will have a different

phase of  $\lambda_g/2 + \lambda_g/2 = \lambda_g$  or  $360^\circ$  (or can be said there is no phase difference), so that they will strengthen each other and result in a high signal reflection [42].

## 5. Extreme beamsquint technique

The ability of beamsquint technique in minimizing the reflected signal from the slots depends on one condition, that is, the number of ring must be sufficient. As an example, **Figure 10a** and **b** shows the reflected signals of a three-ring RLSA antenna and the reflected signals of a two-ring RLSA antenna, respectively. Since every ring consists of two slots, hence, there are six reflected signals for the three-ring RLSA antenna and four reflected signals for the two-ring RLSA antenna. It is assumed that the amplitude of all reflected signals is the same in order to simplify the analysis. From **Figure 10a**, it can be observed that all the graph space is covered by the reflected signals; hence the combination of all reflected signals will cancel out each other, and the minimum signal reflection is obtained. In contrast, from **Figure 10b**, it can be seen that not all graph space (the area pointed by 'A') is covered by the reflected signals; hence the combined signal will be greater than the combined signal in **Figure 10a**.

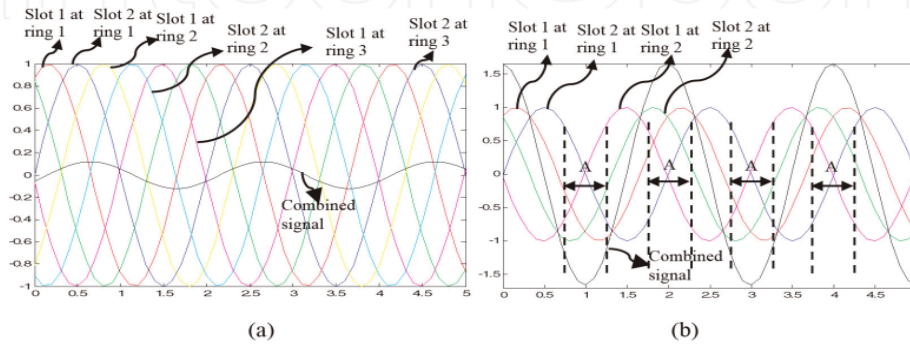
From the example in the previous paragraph, it can be concluded that a smaller number of ring will decrease the ability of beamsquint technique in cancelling the reflected signal. Therefore, this is the reason why the reflection coefficient of small-RLSA antennas, which have few numbers of rings (less than 2), is high and why the normal beamsquint technique fails to minimize the reflection coefficient of small-RLSA antennas. The next section will explain how the proposed extreme beamsquint technique can reduce the high reflection coefficient of small-RLSA antennas by increasing the number of ring.

The position of the ring in radial direction ( $S_p$ ) can be expressed by Eq. (10) [21]:

$$S_p = \frac{r\lambda_g}{1 - \xi \sin \theta_T \cos(\phi - \phi_T)} \quad (10)$$

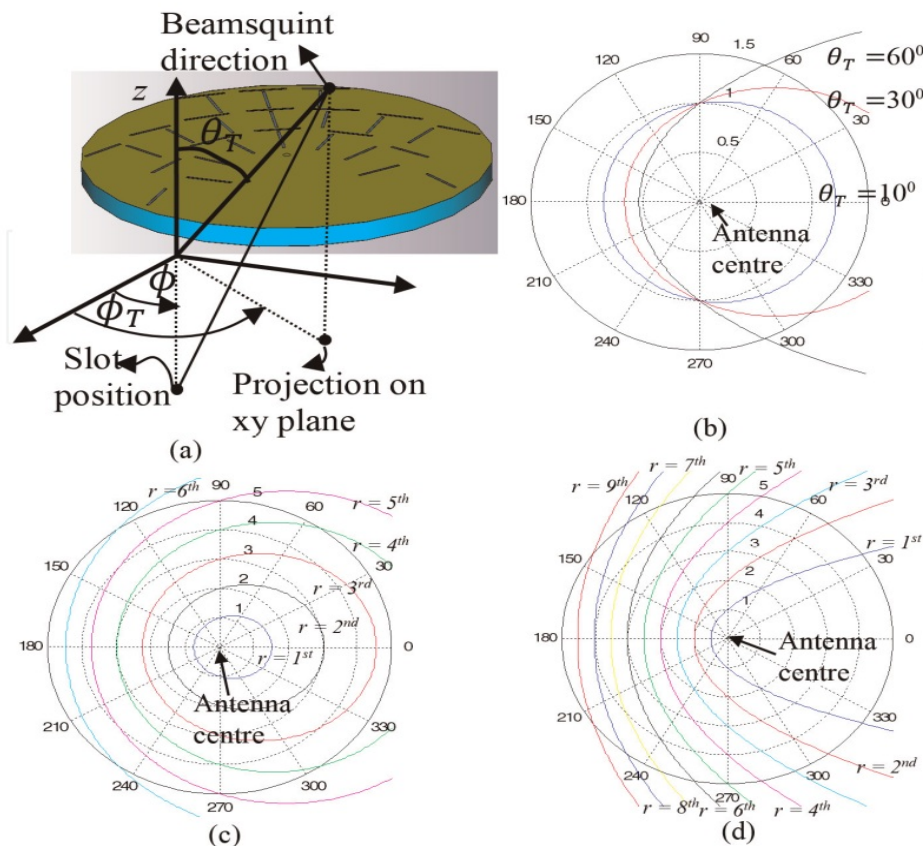
$\theta_T$  is the beamsquint angle,  $\phi$  is the position of slots in azimuth,  $\phi_T$  is the azimuth angle of beamsquint and  $r$  is the ring number. **Figure 11a** illustrates the definition of all this parameters.

Based on Eq. (10), by utilizing  $r = 1$ ,  $\phi_T = 0$  and  $\phi = 0-360^\circ$ , the rings for beamsquint angle of  $10^\circ$ ,  $30^\circ$  and  $60^\circ$  are plotted as shown in **Figure 11b**.



**Figure 10.** (a) Reflected signal of a three-ring RLSA antenna. (b) Reflected signal of a two-ring RLSA antenna [39].





**Figure 11.** (a) Illustration of some parameters of ring position. (b) Plot of the ring for beamsquint of  $20^\circ$ ,  $30^\circ$  and  $60^\circ$ . (c) Plot of various ring numbers for beamsquint angle of  $20^\circ$ . (d) Plot of various ring numbers for beamsquint angle of  $80^\circ$  [39].

It illustrates that the beamsquint technique performs the ring in the shape of ellipse rather than in the shape of circular. From **Figure 11b**, it can be observed that the position of the ring at the left-hand side will move closer to the centre of the antenna as the beamsquint increases. In contrast, the position of the ring at the right-hand side will move farther from the centre of the antenna as the beamsquint increases.

Still based on Eq. 3, by utilizing  $\phi_T = 0$  and  $\phi = 0$  to  $360^\circ$ , the rings are plotted for various ring numbers both for the beamsquint angle of  $20^\circ$  and  $80^\circ$  as shown in **Figure 11c** and **d**, respectively. From these figures, it can be observed that at the left-hand side, the distance between rings for beamsquint angle of  $80^\circ$  is shorter than the distance between the rings for beamsquint angle of  $20^\circ$ . Due to the shorter distance between rings, the beamsquint angle of  $80^\circ$  has more rings (nine rings) that can be plotted in the antenna area compared to the beamsquint angle of  $20^\circ$  (six rings). Based on the previous examples and explanations, it can be concluded that the higher beamsquint angle can yield more rings. This fact is very useful to include additional rings for the small-RLSA antenna, which originally has a low number of rings (less than 2). The extra number of rings will have more ability to minimize the



reflection coefficient of small-RLSA antenna. The use of extra high beamsquint angle underlies the naming of extreme beamsquint technique.

## 6. Future development of RLSA antennas

Space to be explored for RLSA antennas has remained wide, since only few researchers study this topic. This is due to the drawing slots of RLSA antennas that are difficult without using computer programmes. This is unlike microstrip antennas which are easy to draw since their shape is simple. Moreover, it is more difficult to fabricate RLSA antennas compared to microstrip antennas since there is no raw material that is ready to be cut or to be formed. This is unlike microstrip, which can use many types of boards such as FR4. Therefore, due to these reasons, less researchers are interested in studying RLSA antennas than microstrip antennas. Below, several research ideas in the field of RLSA are presented to be explored deeper, especially for doctoral dissertation and master thesis.

### 6.1 Cutting antennas

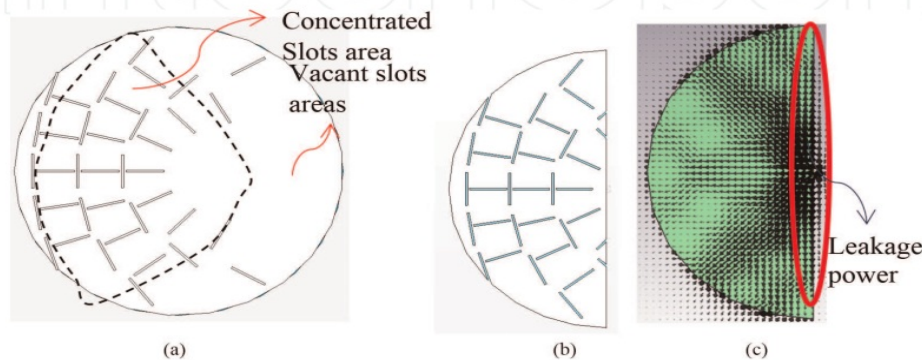
#### 6.1.1 Concentrated slot area

The use of extra high beamsquint results in concentrated slots in a certain area of radiating elements, and leaving other areas vacant from slots, as shown in **Figure 12a**.

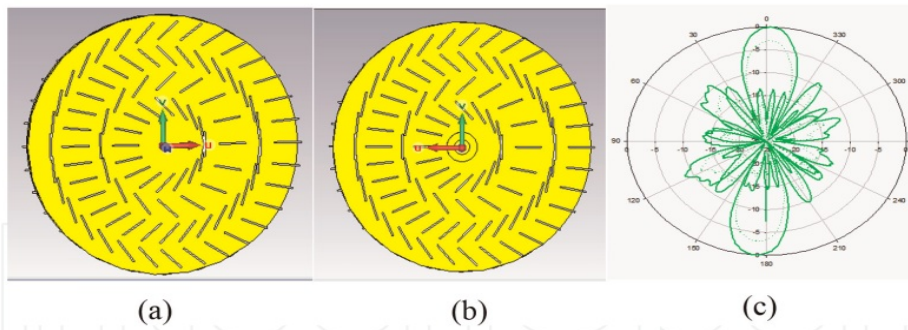
Our hypothesis is that since the vacant area is not useful, then it can be cut off, thus resulting in a smaller antenna, as shown in **Figure 12b**. We have studied that definitely there will be an effect of the cut, which is a leakage power along the cutting line, shown in **Figure 12c**. This leakage power reduces the antenna gain. However, the antenna gain will not be affected significantly since the power density within the cut antenna will increase, thus also will increase the gain, then counteracting the decrease gain due to the leakage power.

### 6.2 The use of background as radiating element

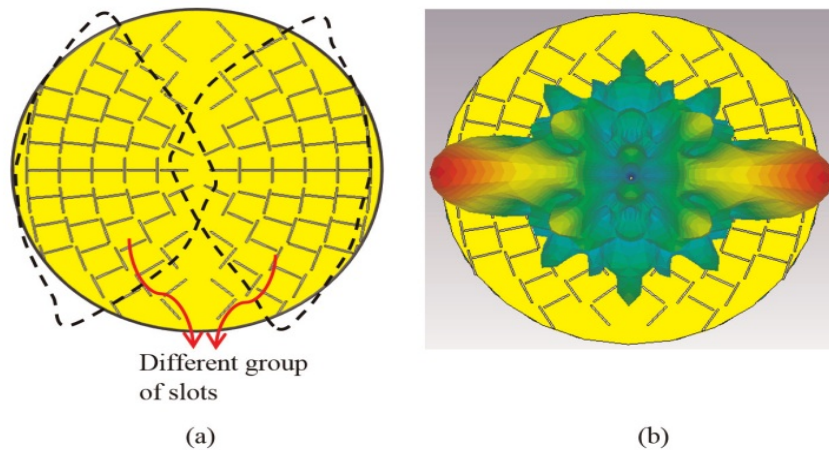
Theoretically, only radiating elements that are used as place for slots, as shown in **Figure 13a**. The background always functions as conventional background to



**Figure 12.**  
(a) Concentrated slots. (b) Cut antennas. (c) Leakage power.



**Figure 13.**  
(a) Radiating element. (b) Background. (c) Radiation pattern.



**Figure 14.**  
(a) Design of dual-beam antenna. (b) Beam result.

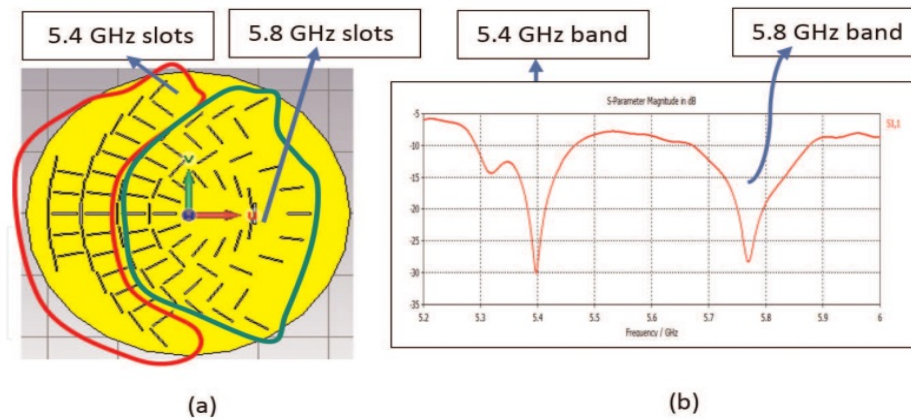
radiating elements. Our hypothesis is that the background can be used to draw slots on it, as shown in **Figure 13b**. This will result in a dual-beam antenna as shown in **Figure 13c**. Of course, the gain will decrease by 3 dB compared to the originally single-beam antenna, since the power is divided into two beams.

### 6.3 Multibeam antennas

Multibeam antennas can be produced by designing slots using different beamsquint values. The slots are grouped and placed based on its beamsquint values. **Figure 14a** shows the slot design of two beams, and **Figure 14b** shows its beams. Things to note are that there will be a slot coupling between adjacent slot groups, which will lessen the sharpness of beams or the gains. Therefore, it is needed to put the slot group not too close together such that we get satisfied gains.

### 6.4 Multiband antennas

Multiband antennas can be produced by designing slots using different frequencies. **Figure 15** shows the slots that are used for two frequencies. It is noted that we



**Figure 15.**  
(a) Design of dual-band antenna. (b) Band result.

cannot differentiate between the 5.4 and 5.8 GHz slots since they are plotted mixed. This will not effect to the gain since all slots are designed using a same beamsquint value. Research on this topic can be as follows: firstly, a study on how to correctly place different frequency slots, so that the correct placement will not increase antenna reflections. Secondly, a study of how far two different bands or more can be separated since a different band needs a different feeder structure. However in multiband antennas, we use a same feeder structure so that it will effect to the increase of reflection, such that different bands cannot be separated too far.

## 7. Conclusions

RLSA antennas have been developed since the 1980s until nowadays. They were initially developed for satellite receiver antennas. Due to their advantages, such as high gains and flat shapes, these antennas have been also developed for small device applications at smaller frequencies, such as Wi-Fi, 5th G, 4th G, etc. However developing RLSA antennas for small device applications had been facing the problem of high signal reflections, due to the limited number of slots. Several techniques had been proposed to overcome the problem. Among the techniques, the extreme beamsquint technique is the most effective technique in reducing signal reflections. By resolving the problem of signal reflections, the research areas for RLSA antennas become wide open, especially for multibeam RLSA antennas, multiband RLSA antennas and size minimization by cutting RLSA antennas.

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